

# Timing of ACL injuries during elite male football (soccer) matches—Impact of player position, substitutes, contact mechanisms, possession status and situational pattern: An analysis of 369 ACL injuries

Matthew Buckthorpe<sup>1,2,3</sup>  | Stefano Di Paolo<sup>2,4</sup> | Alberto Grassi<sup>4</sup> | Filippo Toserelli<sup>2</sup> | Francesco Della Villa<sup>2</sup>

<sup>1</sup>Faculty of Sport, Technology and Health Sciences, St Mary's University, Twickenham, London, UK

<sup>2</sup>Education and Research Department, FIFA Medical Centre of Excellence, Isokinetic Medical Group, Bologna, Italy

<sup>3</sup>Isokinetic Medical Group, FIFA Medical Centre of Excellence, London, UK

<sup>4</sup>2nd Orthopedic and Traumatologic Clinic, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy

## Correspondence

Matthew Buckthorpe, Twickenham, Faculty of Sport, Technology and Health Sciences, St Mary's University, Waldegrave Rd, Twickenham, London TW1 4SX, UK.  
Email: [matthew.buckthorpe@stmarys.ac.uk](mailto:matthew.buckthorpe@stmarys.ac.uk)

## Abstract

**Purpose:** To document the timing of anterior cruciate ligament (ACL) injuries according to match minute and effective minutes played during football matches, considering player position, substitutions, contact mechanism, possession status and situational pattern.

**Methods:** This was a subsequent analysis of previously published video analysis studies of ACL injuries in professional men's football. Only those injuries with videos in which the exact moment of the injury could be determined were included. For each video, we were concerned with the phase of the game when the ACL injury occurred (match minute) and the number of minutes played by the ACL injured player, correcting for substitutions. To allow for comparison of injury distribution across categories, frequency was reported as percentage observations in each respective time window (15 min). The relative risk (RR) of sustaining an ACL injury in the different 15-min periods was computed. Significance testing (one-way analysis of variance or independent *t*-test) and regression analysis were performed to determine differences in timing for the categories.

**Results:** Injury timing data were reported for 369 ACL injuries. More injuries occurred during the first ( $n = 216$ , 59%) than second ( $n = 153$ , 41%) half ( $p < 0.01$ ). When considering the minutes played, 87 (24%), 167 (46%) and 246 (67%) ACL injuries occurred in the first 15, 30 and 45 min, respectively. RR for all injuries for each 15-min period was  $>1$  in the first 45 min of effective gameplay and  $<1$  in the second 45 min. Substitutes had a significantly earlier ACL injury timing than starters ( $19.7 \pm 20.1$  vs.  $39.7 \pm 24.3$  min,  $p < 0.001$ ), with high RR in the first 15 min (3.21).

**Conclusions:** More ACL injuries occur in the first 45 min of match play; among substitutes injuries occur 20 min earlier than in starters. Higher match intensity and lack of preparation (e.g., warm up) are likely explanatory.

**Abbreviations:** ACL, anterior cruciate ligament; ANOVA, analysis of variance; ATT, attacker; DC, direct contact; DEF, defender; IC, indirect contact; LFJ, landing from jump; MID, midfielder; NC, non-contact; RBAK, regaining balance after kicking; RR, relative risk.

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2025 The Author(s). *Knee Surgery, Sports Traumatology, Arthroscopy* published by John Wiley & Sons Ltd on behalf of European Society of Sports Traumatology, Knee Surgery and Arthroscopy.

**Level of Evidence:** Level IV.

**KEYWORDS**

ACL injuries, ACL injury, context, fatigue, injury aetiology, injury mechanism, injury prevention, timing

## INTRODUCTION

Reducing injury burden is of utmost importance for the medical and performance team in football (soccer) due to the financial and team performance implications of injury burden [20, 22, 32]. Anterior cruciate ligament (ACL) injuries are a major issue for football teams and the players which experience them. They are career threatening injuries, even at the elite end of football [48, 51], with high injury burden (~100 days per season) [15, 16] and high recurrence rates [8, 12]. They also negatively impact player performance and career longevity [2, 39, 48].

An understanding of injury epidemiology and aetiology is crucial in designing injury risk mitigation programmes [40, 47]. In recent years, several studies have elucidated the injury mechanisms, situational patterns and biomechanics of the injury [9, 11, 13, 48]. A gap in understanding is around the timing of injuries during the match in relation to the number of minutes played. The timing of ACL injuries is thought to reflect the extent of freshness and fatigue of the player. The intensity and volume of football actions place significant loads on the lower limb musculoskeletal system and can result in significant reductions in force capabilities, altered movement quality, and impaired performance and decision-making capacity [5, 7, 14, 21, 37, 42, 43]. While fatigue is often suggested to be implicated in ACL injuries, as a modifiable risk factor [3], previous research on match ACL injury timing suggests that cumulative fatigue is not a risk factor for ACL injury, as generally more injuries occur in the first half [9, 11, 13, 33]. A greater proportion of ACL injuries earlier in the match is suggestive of either ineffective preparation or higher intensities [11, 38, 41], as the main causative factors. However, to date the match timing has typically been a secondary consideration, reported as additional analysis, and research has not considered if timing of ACL injuries in elite football varies across player position, for substitutes versus starters, contact mechanism, possession status or situational patterns. It is plausible that variations in match timing are apparent for these different variables.

The aim of this study was to more clearly elucidate the timing of ACL injuries on a large cohort of injuries, by combining data across cohorts of previously published studies [9, 11, 13] extracting information according to the player position, whether they started the match or were a substitute, contact mechanisms, possession status and situational pattern. It was hypothesised that more injuries would occur in the first

half and with less minutes of effective gameplay. Further, we expect divergence in injury timing across player position, between starters and substitutes, across contact mechanisms, possession status and situational patterns, albeit without certainty on direction of differences.

## MATERIALS AND METHODS

### Study design and injury identification

This was a subsequent analysis of previously published video analysis studies of ACL injuries in professional men's football [9, 11, 13]. Information from the databases of the previously published papers was merged to provide a new large database of ACL injuries. For each study, the 'Quality Appraisal for Sports Injury Video Analysis Studies (QA-SIVAS) scale' [24] was used and reported a score of 16/18 (excellent) for each respective study (see Supporting Information: Table 1).

Each study adopted the same methods. To summarise, we adopted a cross-sectional retrospective observational study design. We systematically searched online database resources. For the Italian cohort [11], injuries were captured across 10 consecutive seasons (from 2008/2009 to 2018/2019, until December 2018) to identify ACL injuries occurring during matches in players of Italian first (Serie A) and second (Serie B) division professional football teams. For the Spanish cohort [9], injuries were captured across 12 seasons (from 2010/2011 to 2021/2022 until May 2022) to identify ACL injuries occurring during matches in players of the two top leagues in Spain, La Liga and La Liga 2. For the English cohort [13], ACL injuries were captured across 11 seasons (from 2010–2011 to 2020–2021 until February 2021) to identify ACL injuries occurring in players on the English Premier and Championship teams. All studies included domestic league matches, as well as friendly, domestic and international cup and national team (Italy, Spain and England) matches.

Briefly, those studies identified ACL injuries via Transfermarkt.de (Transfermarkt GmbH & Co. KG, Hamburg, Germany), following extraction of each season and team's players list from on-line databases (legaseriea.it; legab.it). This methodology has been validated for injuries identification in professional football [30] and adopted by studies on return to play in

professional football [31, 39]. We supplemented this search by examining further data sources that may have been missed, including national and local media. Injuries were included only when we could corroborate the injury with official team media reports. Only injuries involving complete ACL rupture were included.

## Video extraction

Match videos were obtained from an online digital platform (wyscout.com, Wyscout spa, [Genova Italy]). A cloud tool (Digital Log, Digital Soccer Project S.r.l. Modena, Italy) was used to process the match videos. Each ACL injury video was cut to approximately 12–15 s prior to, and 3–5 s post the estimated injury frame to accurately evaluate the playing situation that preceded the injury and injury mechanisms. All the videos we accessed are publicly available, in which data were treated confidentially, and no personal player information was accessed. Therefore, ethical permission was not required [9, 11, 13].

## Video evaluation and defining an ACL rupture

Three reviewers for each of the three studies, all who are involved sport medicine and orthopaedic rehabilitation practice, with experience of video analysis research, independently evaluated the videos, using a checklist (Supporting Information: Table 2). Each video was downloaded on the personal computer and opened with the online available software 'Kinovea' (Kinovealnk), before being analysed using an evaluation flow.

For this study, we were interested specifically on the timing of the ACL injury, and how this may be impacted by playing position (goalkeeper, defender, midfielder and attacker), substitution (starter vs. substitute) the injury contact mechanism (direct, indirect and non-contact), possession status (offensive and defensive) and situational pattern (pressing/tackling, being tackled, landing from jump and regaining balance).

Player position was denoted across goalkeeper, defender (including central defender, right/left back, wingback and sweeper), midfielder (including defensive, central and attacking midfielder, right/left midfielder) and attacker (centre forward, second striker and winger).

In analysis of the videos, the injurious situation was characterised as defensive or offensive, based on ball possession and specific playing situation was determined. A series of views were then used to determine the injury contact mechanism and situational pattern. Three categories of injury mechanism were used: (1) non-contact, defined as an injury occurring without any contact (at the knee or any other level) prior to or at injury frame; (2) indirect contact, defined as an injury

resulting from an external force applied to the player, but not directly to the injured knee and (3) direct contact, defined as external force directly applied to the injured knee. Based on previous findings we considered the estimation of injury frame, as initial contact (plus 40 ms) [9, 11, 13, 25, 26].

In the three studies, the term 'situational pattern' was used to determine the playing action and context of the injury. This was performed for noncontact and indirect contact injuries only and was categorised into four main patterns: (1) pressing/tackling, (2) being tackled, (3) landing from jump and (4) regaining balance after kicking. Any injuries that did not fit those patterns were categorised as other. In each of the three studies, the reviewers met for a 1-day meeting to achieve consensus on all items regarding injury mechanism and situational patterns. Disagreements were resolved via consensus [9, 11, 13]. Prior the meeting, the intra-class correlation index between the reviewers for the initial contact and injury frame was 0.98–0.99 across studies.

## Match distribution

For each available injury video, we recorded the phase of the game when the ACL injury occurred (minute and half) and the number of minutes played by the ACL injured player, correcting for substitutions. Only those injuries with video data, in which the exact moment of the injury could be determined were included. To allow for comparison of injury distribution across categories (e.g., player position, contact mechanisms, possession status and situational patterns), frequency was reported as percentage observations in each respective time window. Data for all injuries were reported in both 5-min (e.g., 0–5, 6–10, etc.) and 15-min (e.g., 0–15, 16–30, etc.) windows, while when categorised across player position, starting status, contact mechanism, possession status and situational pattern, data were reported only for 15-min windows using effective minutes played only.

## Statistical analysis

Continuous variables were presented as mean ( $\pm$ standard deviation) or median (range) as appropriate according to variables distribution. Normal distribution was verified through the Shapiro–Wilk test. Discrete variables were presented as absolute numbers and percentage on the number of total observations. The proportion test was used to explore possible differences in the distribution of ACL injuries between match halves.

The relative risk (RR) of sustaining an ACL injury in the different 15-min windows (time periods) was computed.  $RR > 1$  indicated a greater risk of sustaining the injury in a time period than the equal distribution, while

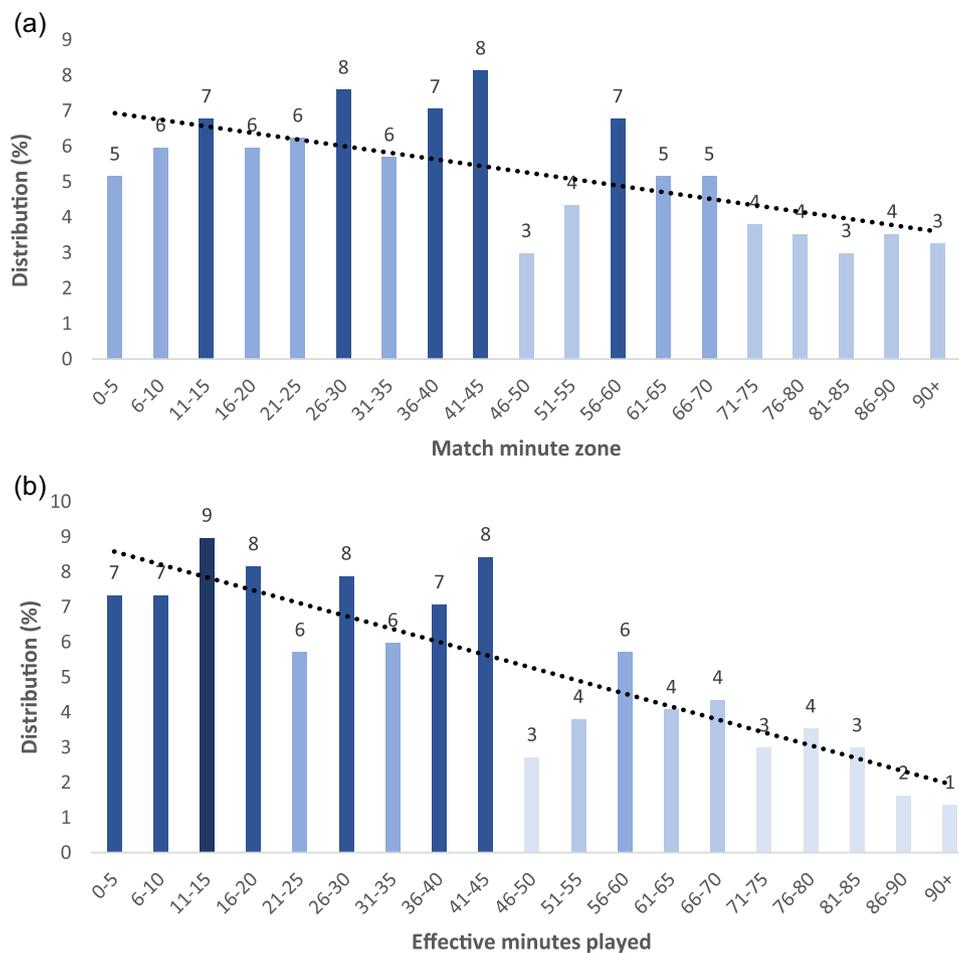
RR < 1 indicated a lower risk. The chi-squared test within contingency tables was adopted to compute the differences in injury risk across the six-time windows for the following factors: player position, starter versus substitution, ball possession, injury mechanism, situational pattern. When significant differences were observed, single 2 × 2 contingency tables with Bonferroni correction for *p*-value were computed. The one-way analysis of variance (ANOVA) and the independent *t*-test were adopted to inspect differences in effective minutes played for the same factors, according to the number of features. Post-hoc comparisons with Bonferroni correction for *p*-values were performed in case of significant differences in the ANOVA. Partial eta squared and Cohen's *d* were reported as effect size measure accordingly. Multivariate linear regression analysis was computed to inspect the effect of the factors on minute of effective gameplay of ACL injury occurrence. Factors with negative (–) regression coefficients β contributed to an earlier injury occurrence. An alpha less than 0.05 denoted statistical significance. Microsoft Excel 2016 (Microsoft, USA) and Stata 12 (Statacorp, Texas, USA) were used for all the statistical analyses.

## RESULTS

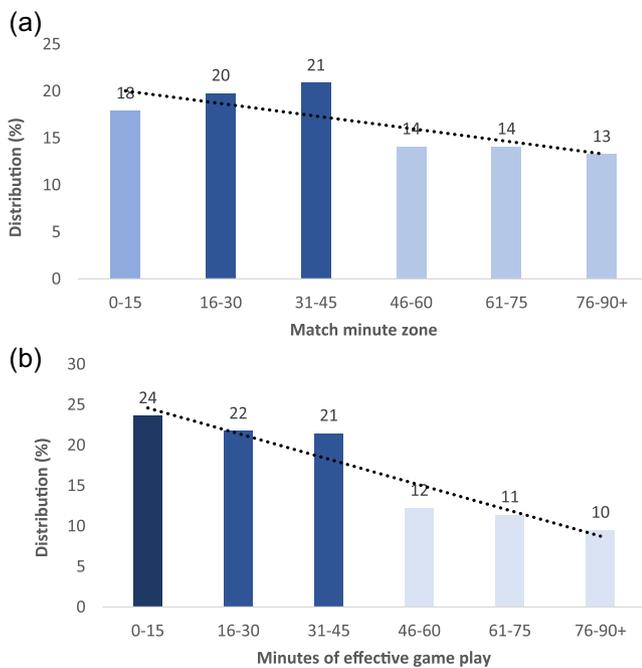
Three hundred and sixty-nine ACL injury videos with identifiable time via video analysis were included. Injuries across leagues are documented in Supporting Information: Table 3. There were 214 (58%) injuries to the right and 153 (42%) injuries to the left ACL, with 205 (56%) injuries to the dominant kicking leg and 162 (44%) to the non-kicking leg (two unknown injuries). There were 308 primary ACL injuries and 61 re-injuries (28 contralateral native; 28 ipsilateral graft re-injuries; five tertiary ACL injuries). Video footage was available and identifiable for situational pattern and injury mechanism analysis in 367 cases (99%).

### All injuries

More injuries occurred during the first (*n* = 216, 59%) than second (*n* = 153, 41%) half (*p* < 0.01) (Figure 1a). The highest 5-min periods were 26–30 and 41–45 min, with 8%, but three other periods with similar (7%), 11–15, 36–40 and 56–60.



**FIGURE 1** Distribution of anterior cruciate ligament (ACL) injuries throughout the match according to match minute and specific 5-min time zone/period (a) (*n* = 369) and minutes of effective playing time (b) (*n* = 368). Dashed lines represent the linear trend line.



**FIGURE 2** Distribution of anterior cruciate ligament (ACL) injuries throughout the match according to match minute and specific 15-min time zone/period (a) ( $n = 369$ ) and minutes of effective playing time (b) ( $n = 368$ ). Dashed lines represent the linear trend line.

When reporting injuries for effective match minutes across 5-min periods, 11–15 min was the highest (9%), with similarly high (8%) 5-min periods of 16–20, 26–30 and 41–45 (Figure 1b).

When reporting according in 15-min periods, there was a gradual increase in injuries across the first half (18%, 20% and 21% for each 15-min period, respectively, Figure 2a), with a consistent but lower proportion across each 15-min periods of the second half (13%–14%). When considering the minutes played, correcting for substitutions, 87 (24%), 167 (46%) and 246 (67%) ACL injuries occurred in the first 15, 30 and 45 min, respectively (Figure 2b), with the highest 15-min period being 0–15 min. RR for all injuries for each 15-min period was  $>1$  in the first 45 min of effective gameplay and  $<1$  in the second 45 min, with the first 15 min having an RR + 42% (1.42; Table 1).

## Player position

Injuries occurred in 14 (4%) goalkeepers, 129 (36%) defenders, 120 (33%) midfielders and 100 (28%) attackers. There was no significant difference in timing of ACL injuries between positions (Table 2,  $p = 0.218$ ). RR for all outfield players was overall  $>1$  in the first 45 min of effective gameplay and  $<1$  in the second 45 min. Attackers (1.68) and midfield (1.45, although the 30–45-min period was similar, RR, 1.40) players had their highest RR in the first 15 min and defenders (1.58)

in the second 15-min period of effective gameplay. Goalkeepers had their highest RR (2.18) in the final 15 min of effective gameplay, in which 36% of goalkeeper injuries occurred (Table 1 and Figure 3).

## Starter versus substitute

ACL injuries occurred in 330 starters and 39 substitutes. Substitutes had a significantly earlier ACL injury timing than starters ( $19.7 \pm 20.1$  vs.  $39.7 \pm 24.3$ ,  $p < 0.001$ , Table 2). The RR for substitutes in the first 15 min (3.21) was substantially higher than all other periods ( $<1.21$ ). 78% of all substitute injuries occurred in the first 30 min of effective gameplay. RR for starters was overall  $>1.21$  in the first 45 min of effective gameplay and  $<0.80$  in the second 45 min, but with the highest RR being in the 30–45-min period (1.37, Table 1).

## Timing and contact mechanism

We categorised 55 (15%) direct contact, 153 (42%) indirect contact and 157 (43%) non-contact injuries. There was no difference in average timing across contact mechanisms ( $p = 0.217$ , Table 2). Both indirect and non-contact had RR  $> 1$  for the periods in the first 45 min and RR  $< 1$  for all periods in the final 45 min (Table 1).

## Timing and possession status

More injuries occurred in defensive ( $n = 234$ , 64%) than offensive ( $n = 132$ , 36%) situations ( $p < 0.001$ ), with no difference in mean ACL injury time between groups ( $p = 0.263$ , Table 2). RR for defensive and offensive injuries was overall  $>1$  in the first 45 min of effective gameplay and  $<1$  in the second 45 min (Table 1).

## Timing and situational pattern

Situational patterning was performed for indirect and non-contact injuries only ( $n = 310$ ). We categorised 271 injuries (87% of all indirect and non-contact injuries) across the four main situational patterns: (1) Pressing/tackling ( $n = 147$ , 47%); (2) being tackled ( $n = 55$ , 18%); (3) landing from jump ( $n = 37$ , 12%); and (4) regaining balance after kicking ( $n = 32$ , 10%). The other 39 (13%) injuries were classified as other and not presented. There was no significant effect of situational patterns on ACL injury timing ( $p = 0.445$ , Table 2). Pressing/tackling and regaining balance after kicking both had RR  $> 1$  for each period in the first 45 min, and RR  $< 1$  for each period in the final 45 min. Pressing/tackling had

**TABLE 1** Relative risk (RR) for minutes of effective gameplay according to relevant match and injury factors.

	Minutes of effective gameplay					
	0–15	16–30	31–45	46–60	61–75	76–90+
All	1.42	1.30	1.29	0.73	0.68	0.57
Possession status						
Offensive	1.45	1.14	1.23	0.68	0.68	0.82
Defensive	1.41	1.36	1.33	0.77	0.69	0.44
Starter-substitution						
Starter	1.21	1.26	1.37	0.80	0.71	0.64
Substitution	3.41	1.30	0.65	0.16	0.49	0.00
Injury mechanism						
Non-contact	1.49	1.57	1.22	0.65	0.61	0.46
Indirect contact	1.37	1.14	1.18	0.86	0.63	0.82
Direct contact	1.42	0.76	1.85	0.65	1.09	0.22
Position						
Goalkeeper	0.86	0.86	1.29	0.43	0.43	2.14
Defender	1.16	1.58	1.35	0.74	0.60	0.56
Midfielder	1.45	1.15	1.40	0.75	0.70	0.55
Attacker	1.68	1.26	1.14	0.78	0.72	0.42
Situational pattern						
Pressing/tackling	1.47	1.47	1.43	0.73	0.45	0.45
Being talked	1.75	0.87	0.76	0.55	1.31	0.76
Landing from jump	0.97	1.78	0.81	0.97	0.49	0.97
Regaining balance after kicking	1.16	1.74	1.16	0.58	0.97	0.39

Note: RR > 1: greater risk of sustaining the injury in a time period than the equal distribution; RR < 1: lower risk.

consistent RR values across each of the three 15-min periods in the first 45 min of effective gameplay (RR, 1.43–1.47). The last 30 min of effective game time represented low risk (RR, 0.45). Regaining balance after kicking had a high RR in the 15–30-min period (1.74) and very low RR in the final 15 min (0.39). Landing from a jump had a differing profile with the highest RR 15–30 min (1.78). Being tackled had its highest RR in the first 15 min (1.75), but with a second peak in the 60–75-min period (1.31). All other periods were <1 (Table 1).

## Regression model

Regression models showed significant interaction for effective gameplay ( $R^2 = 0.06$ ,  $p < 0.001$ ). Being a substitution player and being an attacker were significantly associated with an earlier occurrence of ACL injury during the game (20.6 min earlier for substitution

compared to starters, 14.7 min earlier for attackers compared to goalkeepers, Table 3).

## DISCUSSION

The main findings of the study were that more injuries occurred in the first half (59%) than second half (41%) and 24%, 46% and 68% of injuries occurred in the first 15, 30 and 45 min of effective gameplay. Player position for all outfield positions showed a similar trend to the typical pattern, except for divergence for goalkeepers (50% of injuries in first 45 min of effective gameplay), with attackers experiencing an earlier ACL injury than goalkeepers. Substitutes experienced an earlier ACL injury than starters. Mean timing of injuries was not affected by contact mechanism, possession status or situational pattern, although there was some divergence in RR across differing 15-min periods of effective gameplay.

**TABLE 2** Differences in minutes of effective gameplay according to relevant match and injury factors.

	Minutes of effective gameplay	p value	Effect size
Starter-substitution		<0.001	0.83 <sup>a</sup>
Starter	39.7 ± 24.3		
Substitution	19.7 ± 20.1		
Injury mechanism		0.217	0.008 <sup>b</sup>
Non-contact	35.2 ± 23.6		
Indirect contact	40.1 ± 25.8		
Direct contact	37.9 ± 24.0		
Position		0.218	0.012 <sup>b</sup>
Goalkeeper	49.7 ± 26.8		
Defender	37.9 ± 23.7		
Midfielder	37.9 ± 25.2		
Attacker	35.2 ± 24.3		
Possession status		0.263	0.12 <sup>a</sup>
Offensive	39.5 ± 26.5		
Defensive	36.5 ± 23.5		
Situational pattern		0.445	0.013 <sup>b</sup>
Pressing/tackling	33.1 ± 22.4		
Being talked	39.1 ± 26.1		
Landing from jump	41.6 ± 26.2		
Regaining balance after kicking	38.1 ± 24.5		

Abbreviation: ANOVA, analysis of variance.

<sup>a</sup>Cohen's *d* (*t*-test).

<sup>b</sup>Partial eta squared (ANOVA).

This study provides strong evidence that more injuries occur in the first half of the match and first 45 min of effective match play. Two of every three injuries occurred in the first half, with two-thirds (67%) in the first 45 min of effective match play. This finding supports previous research [9, 11, 13], providing strong confirmation of evidence on a large sample of ACL injuries ( $n = 369$ ). An earlier ACL injury occurrence in the match suggests that cumulative fatigue throughout match play is unlikely a major risk factor for ACL injuries. Instead, factors associated with earlier aspects of match play including lack of physical preparedness [11], intensity of engagements/match play [21, 38, 41] and freshness (as opposed to fatigue) may be more important. This does not indicate that cumulative fatigue is not implicated in ACL injury aetiology, as some injuries latter in the match could have been fatigue impacted, but instead that accumulated fatigue throughout match play is unlikely the *main* factor

associated with all ACL injuries. It is plausible there are differing aetiology for different ACL injuries. ACL injuries are considered complex [4, 46], and interrelations of multiple risk factors likely explain their causation [4]. It is likely that early ACL injuries occurring after shorter game time are associated with lack of preparation (a mismatch in preparation and game intensity), as well as higher game intensity in general, while injuries later in the match were more fatigue implicated. Importantly, as an experimental model, timing of ACL injuries during the match is considered indirect evidence for the role of fatigue. It does not mean that those who got injured later in the match, experienced high levels of fatigue, and indeed fatigue resistance is highly individual [10, 19, 44, 50] and impacted by training status [44]. Furthermore, this approach does not consider acute fatigue, which is a transient reduction in performance/function because of intense anaerobic activity [8, 37]. It is plausible that at the time of injury in the earlier periods, that while players were fresh (i.e., not experiencing accumulative fatigue because of match play), they may have been experiencing acute fatigue because of intense engagements at that moment. Further research documenting the potential of acute fatigue at the time of injury is warranted. Additionally, this experimental approach does not consider residual fatigue between matches, or more chronic fatigue (e.g., over-reaching and over-training) [36] because of multiple matches, which could still be implicated in those injuries occurring earlier in the match. The high intensity and volume of football actions (e.g., accelerations/sprints, decelerations and change of directions, jump and lands and tackles) leads to declines in neuromuscular function at the end of match play, which can take 72 h to recover from [10]. Research to examine the role of residual and chronic fatigue in ACL injury aetiology is also warranted. Previous research for football injuries, and other pathologies, suggests that acute spikes in training load (indicative of overload and potential over-reaching state) [36] is associated with footballing non-contact injuries [6, 17, 35], and the role of training load in ACL injury causation needs elucidating.

This is the first study to consider player position and timing of ACL injuries. The similar timing of ACL injuries for outfield players suggests similar aetiology between positions, although further research to document positional influence on injury mechanisms and playing context is warranted. While goalkeepers reported an elevated number of injuries towards the end of the match (36% in the final 15 min), it is unlikely due to 'physical' fatigue, as match outputs are typically low versus outfield players [49]. It is plausible, mental fatigue may have been implicated [1], potentially impacting decision making, although game context, such as the score, and activity are more likely. The overall number of goalkeeper ACL injuries was low ( $n = 14$ ). The low

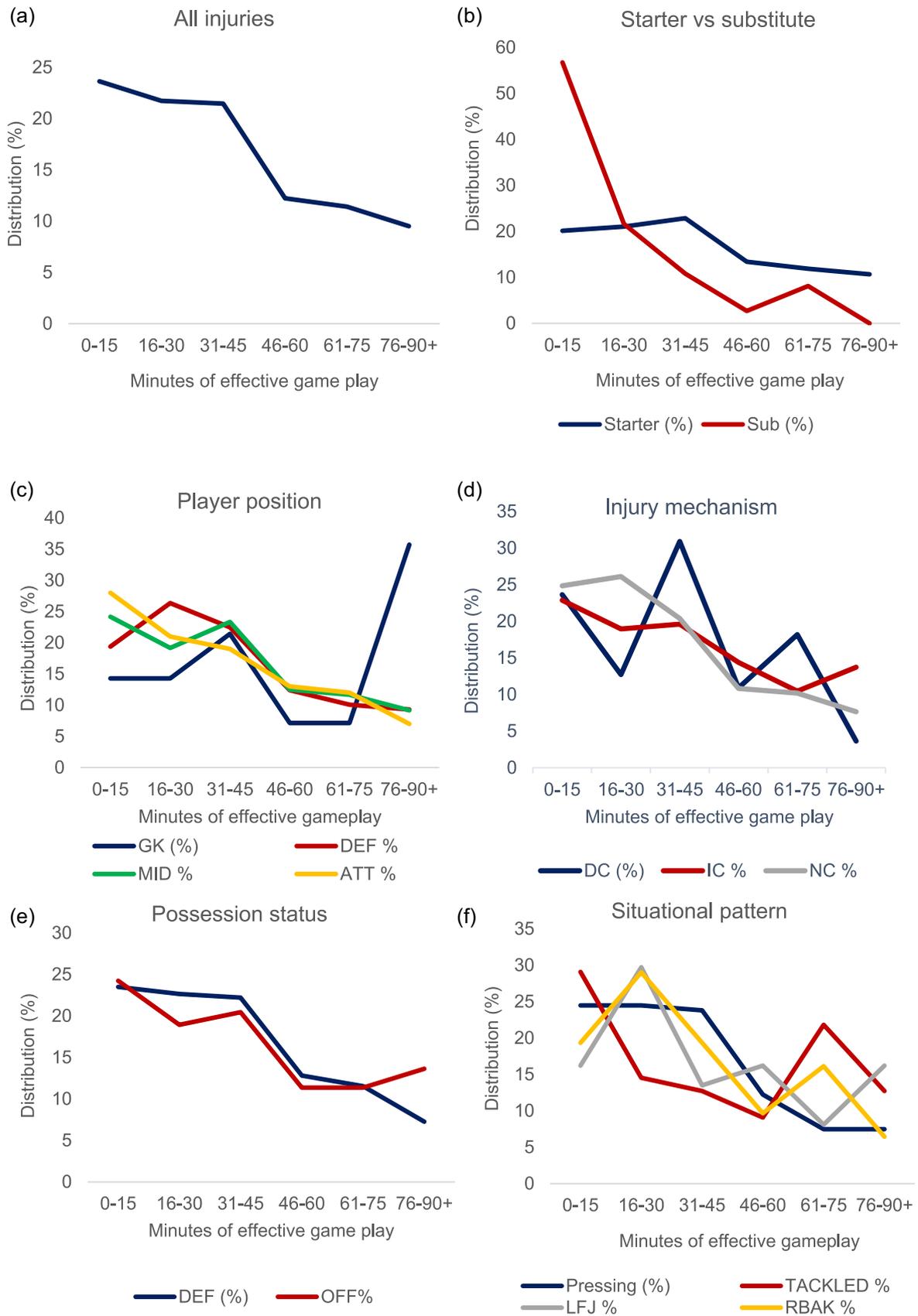


FIGURE 3 (See caption on next page).

**TABLE 3** Regression model describing the interaction between minutes of effective gameplay and relevant match and injury factors.

Metric	Minutes of effective gameplay adjusted- $R^2 = 0.06$ , $p < 0.001$		
	$\beta$	95% CI	$p$ value
Intercept ( $H_1$ )	58.1	[40.9–75.4]	<0.001
Possession status			
Offensive	Ref		
Defensive	-11.6	[-25.7 to 2.6]	0.108
Starter-substitution			
Starter	Ref		
Substitution	<b>-20.6</b>	<b>[-28.9 to -12.3]</b>	<b>&lt;0.001</b>
Injury mechanism			
Direct contact	Ref		
Non-contact	-4.9	[-14.9 to 5.1]	0.334
Indirect contact	-0.3	[-8.2 to 7.7]	0.949
Position			
Goalkeeper	Ref		
Defender	-11.6	[-25.7 to 2.6]	0.108
Midfielder	-10.6	[-25 to 3.9]	0.151
Attacker	<b>-14.7</b>	<b>[-29.1 to -0.3]</b>	<b>0.046</b>
Situational pattern			
Pressing/tackling	-3.8	[-14.7 to 7.1]	0.495
Being talked	-3.3	[-13.8 to 7.1]	0.529
Landing from jump	-0.7	[-12.1 to 10.7]	0.905
Regaining balance after kicking	0.7	[-10.7 to 12.0]	0.910

Abbreviation: CI, confidence interval.

proportion of goalkeeping injuries likely reflects the movement demands of this position, involving fewer high intensity decelerations and change of directions, and more vertical jump-landings actions [49].

Perhaps the most important finding from this paper was the earlier injury timing of substitutes versus starters. Substitutes were injured 20 min earlier on average than starters. The first 15 min of effective gameplay was very high for substitutes (3.21), in relation to starters (1.21). It is likely the much earlier ACL injury

timing for substitutes was associated with lack of physical, mental and technical/tactical preparation. Research suggests that substitutes operate at a higher physical intensity than other players around them, by using an all-out running strategy [23], knowing that they do not need to pace themselves for the full match, potentially like starters. As such, we suggest a mismatch in physical preparation and game intensity amongst those players injured. Further research documenting potential differences in ACL mechanisms, situational patterns, neurocognitive errors and biomechanics between starters and substitutes would further benefit our understanding of ACL injury aetiology in football. Further consideration of warm up practices of substitutes may be necessary to mitigate injury risk. Even when factoring in the impact of substitutions, starters still had 64% of injuries in the first 45 min of effective gameplay (down from 68% when including substitutes).

Contact mechanism did not impact ACL injury timing. There was slight deviation in the shape of the time curve, with differing RR across which likely reflect game context (e.g., more direct contact injuries during periods of expected intense physical engagements) [41].

Possession status seemed to have minimal influence on the timing of ACL injuries, with both defensive and offensive injuries being more prevalent in the first 45 min of effective match play. This likely relates to minimal deviation in timing across situational patterns (see below), as most defensive injuries are pressing/tackling and most offensive injuries are typically being tackled. If situational patterns show similar trends to each other, then possession status likely reflects this. Of note, offensive injuries had a higher proportion of injuries in the final 15 min (14%, RR, 0.82) than defensive injuries (7%, RR, 0.42), suggesting the final period of the match, offensive ACL injuries are more likely, at least when comparing to defensive injuries. This may relate to a slight increase of indirect contact injuries and landing from jump (see below) in this period, potentially due to aerial challenges in the final minutes of the match. Further work considering if this was score related (e.g., the losing team more likely to experience injuries), as well as how the score at the time of injury would provide further insights into ACL injury causation.

While the average timing of injuries did not differ across situational patterns, there was some deviation in RR between 15-min periods in the match. Pressing/tackling

**FIGURE 3** Injury distribution as a percentage of injuries according to effective game minutes played, separated into 15-min window periods according to (a) all injuries ( $n = 368$ ); (b) starters ( $n = 330$ ) vs. substitutes (Sub,  $n = 38$ ); (c) player position including goalkeeper (GK,  $n = 14$ ), defender (DEF,  $n = 129$ ), midfielder (MID,  $n = 120$ ) and attacker (ATT,  $n = 100$ ); (d) contact mechanism, including direct contact (DC,  $n = 55$ ), indirect contact (IC,  $n = 152$ ) and non-contact (NC,  $n = 157$ ); (e) Possession status, starters ( $n = 330$ ) and substitutes ( $n = 38$ ); possession status, defensive ( $n = 234$ ) and offensive injuries ( $n = 132$ ); and (f) situational pattern for indirect and non-contact injuries only including, pressing/tackling (Pressing,  $n = 147$ ), being tackled (Tackled,  $n = 55$ ), landing from jump (LFJ,  $n = 37$ ) and regaining balance after kicking (RBAK,  $n = 32$ ).

and being tackled had their highest RR in the first 15 min (although it was similar throughout the half for pressing/tackling), while landing from jump and regaining balance both had their highest RR in the second 15-min period. This could relate to game context, as teams battle to impose themselves on the match, with intense pressing and tackling in the first 15-min period [41].

Pressing/tackling showed a consistent high RR throughout the first half and low RR in the second half, suggesting the first half is particularly risky. Nearly half (47%) of the indirect and non-contact ACL injuries are pressing/tackling and as such understanding the aetiology of this pattern is important. Only 29% of pressing/tackling injuries occurred in the last 45 min of effective gameplay. This suggests these injuries are influenced by game intensity injuries and potentially due to lack of preparation or player/game awareness. Pressing actions indicative on many ACL injuries in football involve high intensity horizontal deceleration actions [9, 11, 13]. Research has shown there is a second half decline in the distance spent decelerating at moderate and high intensities [21]. This may mean players are exposed to less inciting situations in the second half thereby reducing injury risk. This would suggest that ACL injuries are more associated with higher intensity pressing/tackling actions. Pressing injuries are often non-contact in which players display neurocognitive errors often in response to a deceiving action [18]. As the game progresses, its plausible players better understand the opposing players and make less errors in decision making, although further research is warranted. This would suggest that game and opposing player understanding, as well as neurocognitive processing speed, including the ability to dismiss irrelevant information [45, 49, 50], may be implicated. We are moving beyond the concept that ACL injuries are biomechanical only phenomena and recognising the importance of match context [9, 11, 13, 18].

A key strength of this study is the large sample size ( $n = 369$ ) being the largest study using video analysis of ACL injuries. As such, as well as the valuable insights around injury timing, the studies also provide strong confirmation around contact mechanisms, possession status and situational patterns at the time of ACL injury in football players. The limitations around these aspects of the study, subsequently have the same limitations as our previous work [9, 11, 13], which revolves around the retrospective collection of injury data, using the publicly available Transfermarket service, as opposed to gold-standard approach, of prospective data collection and contact with the team [34]. However, as our key focus for this study was injury timing, as opposed to time loss, this impacts this work minimally. Furthermore, video analysis of injuries has some known limitations. However, these are largely associated with limitations of two-dimensional video analysis of kinematics during injurious events, not being gold-

standard [25, 26, 28, 29]. We did not report kinematics in this study, and video analysis is a valid tool for studying the injury context (e.g., mechanisms and playing situations) [27, 28]. Strengths of the study lie in our approach to systematic video analysis from the previously published cohorts [9, 11, 13], including systematic investigation and use of three video raters in each study. A key strength specifically for this study relates around accuracy of the injury timing information. As opposed to relying on publicly available information, we included only those injuries in which we had access to injury video footage and was able to determine the exact minute of the injury. Furthermore, we controlled for effective gameplay, by considering the number of minutes player, correcting for substitutions. As such, this more closely reflects match minutes played as opposed to the minute of the match, thereby providing stronger insight into freshness vs. fatigue. Timing of injuries as an experimental approach lacks scientific rigour. While this goal is in some way to elucidate the importance of accumulative fatigue, we did not document the extent of fatigue. Likewise, most insights relating to game context (e.g., intensity, physical actions) are speculative based on game understanding from previous research. Future research could consider the extent of work performed by the player prior to the injury, as well as considering game intensity at that moment, as opposed to only time played. This would provide greater insight into the potential role of fatigue and/or work and game context in ACL injury aetiology.

## CONCLUSIONS

More ACL injuries occur in the first half, with two-thirds in the first 45 min of effective gameplay. Starters and attackers experience earlier injuries, with similar timing across contact mechanisms, possession status and situational patterns. These earlier injuries likely reflect higher intensities earlier in match play or a mismatch between player preparation and match intensity. Ensuring players are conditioned for game intensity and appropriately prepared for match play (e.g., warm up strategies) is important.

## AUTHOR CONTRIBUTIONS

Matthew Buckthorpe was responsible for the conception and design of the study. Matthew Buckthorpe combined the three separate databases and analysed and interpreted the results. Stefano DiPaolo supported data analysis and ran the statistics. All authors were involved in the data capture, analysis and/or interpretation of the previously published studies. Matthew Buckthorpe wrote the first draft of the manuscript. All authors provided intellectual contribution to the writing and drafting of the manuscript. Matthew Buckthorpe and Francesco DellaVilla are responsible for the overall content as guarantors.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

Raw videos and data supporting the findings of this study are either publicly available and/or included in the supporting information.

## ETHICS STATEMENT

Our study exclusively utilised publicly available videos, and we handled the data with strict confidentiality. No personal player information was accessed and therefore ethical permission was not required.

## ORCID

Matthew Buckthorpe  <https://orcid.org/0000-0002-4925-4031>

## REFERENCES

- Abbott W, Thomas C, Clifford T. Effect of playing status and fixture congestion on training load, mental fatigue, and recovery status in premier league academy goalkeepers. *J Strength Cond Res.* 2023;37(2):375–82.
- Arundale AJH, Silvers-Granelli HJ, Snyder-Mackler L. Career length and injury incidence after anterior cruciate ligament reconstruction in major league soccer players. *Orthop J Sports Med.* 2018;6:2325967117750825.
- Benjaminse A, Webster KE, Kimp A, Meijer M, Gokeler A. Revised approach to the role of fatigue in anterior cruciate ligament injury prevention: a systematic review with meta-analyses. *Sports Med.* 2019;49(4):565–86.
- Bittencourt NFN, Meeuwisse WH, Mendonça LD, Nettel-Aguirre A, Ocarino JM, Fonseca ST. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition-narrative review and new concept. *Br J Sports Med.* 2016;50(21):1309–14.
- Borotikar BS, Newcomer R, Koppes R, McLean SG. Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. *Clin Biomech.* 2008;23:81–92.
- Bowen L, Gross AS, Gimpel M, Bruce-Low S, Li FX. Spikes in acute:chronic workload ratio (ACWR) associated with a 5-7 times greater injury rate in English Premier League football players: a comprehensive 3-year study. *Br J Sports Med.* 2020;54(12):731–8.
- Bradley PS, Sheldon W, Wooster B, Olsen P, Boanas P, Krstrup P. High-intensity running in English FA Premier League soccer matches. *J Sports Sci.* 2009;27(2):159–68.
- Buckthorpe M. Optimising the late-stage rehabilitation and return-to-sport training and testing process after ACL reconstruction. *Sports Med.* 2019;49(7):1043–58.
- Buckthorpe M, Pirlì Capitani L, Olivares-Jabalera J, Olmo J, Della Villa F. Systematic video analysis of ACL injuries in professional Spanish male football (soccer): injury mechanisms, situational patterns, biomechanics and neurocognitive errors - a study on 115 consecutive cases. *BMJ Open Sport Exerc Med.* 2024;10(3):e002149.
- Carmona G, Moreno-Simonet L, Cosio PL, Astrella A, Fernández D, Cadefau JA, et al. Hamstrings on focus: Are 72 hours sufficient for recovery after a football (soccer) match? A multidisciplinary approach based on hamstring injury risk factors and histology. *J Sports Sci.* 2024;42(12):1130–46.
- Della Villa F, Buckthorpe M, Grassi A, Nabiuzzi A, Tosarelli F, Zaffagnini S, et al. Systematic video analysis of ACL injuries in professional male football (soccer): injury mechanisms, situational patterns and biomechanics study on 134 consecutive cases. *Br J Sports Med.* 2020;54:1423–32.
- Della Villa F, Hägglund M, Della Villa S, Ekstrand J, Waldén M. High rate of second ACL injury following ACL reconstruction in male professional footballers: an updated longitudinal analysis from 118 players in the UEFA Elite Club Injury Study. *Br J Sports Med.* 2021;55:1350–7.
- Della Villa F, Stride M, Bortolami A, Williams A, Davison M, Buckthorpe M. Systematic video analysis of ACL injuries in male professional english soccer players: a study of 124 cases. *Orthop J Sports Med.* 2025;13(2):23259671251314642.
- Di Mascio M, Bradley PS. Evaluation of the most intense high intensity running period in English FA premier league soccer matches. *J Strength Cond Res.* 2013;27(4):909–15.
- Ekstrand J, Bengtsson H, Waldén M, Davison M, Khan KM, Hägglund M. Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: the UEFA Elite Club Injury Study from 2001/02 to 2021/22. *Br J Sports Med.* 2022;57(5):292–8.
- Ekstrand J, Krutsch W, Spreco A, van Zoest W, Roberts C, Meyer T, et al. Time before return to play for the most common injuries in professional football: a 16-year follow-up of the UEFA Elite Club Injury Study. *Br J Sports Med.* 2020;54:421–6.
- Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med.* 2016;50(5):273–80.
- Gokeler A, Tosarelli F, Buckthorpe M, Della Villa F. Neurocognitive errors and noncontact anterior cruciate ligament injuries in professional male soccer players. *J Athl Train.* 2024;59:262–9.
- Greig M, Siegler JC. Soccer-specific fatigue and eccentric hamstrings muscle strength. *J Athl Train.* 2009;44(2):180–4.
- Hägglund M, Waldén M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med.* 2013;47:738–42.
- Harper DJ, Carling C, Kiely J. High-intensity acceleration and deceleration demands in elite team sports competitive match play: a systematic review and meta-analysis of observational studies. *Sports Med.* 2019;49(12):1923–47.
- Hickey J, Shield AJ, Williams MD, Opar DA. The financial cost of hamstring strain injuries in the Australian Football League. *Br J Sports Med.* 2014;48:729–30.
- Hills SP, Barwood MJ, Radcliffe JN, Cooke CB, Kilduff LP, Cook CJ, et al. Profiling the responses of soccer substitutes: a review of current literature. *Sports Med.* 2018;48(10):2255–69.
- Hoening T, Rahlf L, Wilke J, Krauß I, Dalos D, Willwacher S, et al. Appraising the methodological quality of sports injury video analysis studies: the QA-SIVAS Scale. *Sports Med.* 2024;54:203–11.
- Koga H, Nakamae A, Shima Y, Bahr R, Krosshaug T. Hip and ankle kinematics in noncontact anterior cruciate ligament injury situations: video analysis using model-based image matching. *Am J Sports Med.* 2018;46:333–40.
- Koga H, Nakamae A, Shima Y, Iwasa J, Myklebust G, Engebretsen L, et al. Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *Am J Sports Med.* 2010;38:2218–25.
- Krosshaug T, Andersen TE, Olsen OEO, Myklebust G, Bahr R. Research approaches to describe the mechanisms of injuries in sport: limitations and possibilities. *Br J Sports Med.* 2005;39:330–9.
- Krosshaug T, Nakamae A, Boden B, Engebretsen L, Smith G, Slauterbeck J, et al. Estimating 3D joint kinematics from video sequences of running and cutting maneuvers—assessing the accuracy of simple visual inspection. *Gait Posture.* 2007;26:378–85.

29. Krosshaug T, Slauterbeck JR, Engebretsen L, Bahr R. Biomechanical analysis of anterior cruciate ligament injury mechanisms: three-dimensional motion reconstruction from video sequences. *Scand J Med Sci Sports*. 2007;17(5):508–19.
30. Leventer L, Eek F, Hofstetter S, Lames M. Injury patterns among elite football players: a media-based analysis over 6 seasons with emphasis on playing position. *Int J Sports Med*. 2016;37:898–908.
31. Locks R, Utsunomiya H, Briggs KK, McNamara S, Chahla J, Philippon MJ. Return to play after hip arthroscopic surgery for femoroacetabular impingement in professional soccer players. *Am J Sports Med*. 2018;46:273–9.
32. López-Valenciano A, Ruiz-Pérez I, García-Gómez A, Vera-García FJ, De Ste Croix M, Myer GD, et al. Epidemiology of injuries in professional football: a systematic review and meta-analysis. *Br J Sports Med*. 2020;54:711–8.
33. Lucarno S, Zago M, Buckthorpe M, Grassi A, Tosarelli F, Smith R, et al. Systematic video analysis of anterior cruciate ligament injuries in professional female soccer players. *Am J Sports Med*. 2021;49:1794–802.
34. Lundblad M, Häggglund M, Thomeé C, Hamrin Senorski E, Ekstrand J, Karlsson J, et al. Medial collateral ligament injuries of the knee in male professional football players: a prospective three-season study of 130 cases from the UEFA Elite Club Injury Study. *Knee Surg Sports Traumatol Arthrosc*. 2019;27:3692–8.
35. Malone S, Roe M, Doran DA, Gabbett TJ, Collins K. High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *J Sci Med Sport*. 2017;20(3):250–4.
36. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, et al. European College of Sport Science/American College of Sports Medicine. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc*. 2013;45(1):186–205.
37. Mohr M, Krstrup P, Bangsbo J. Match performance of high standard soccer players with special reference to development of fatigue. *J Sports Sci*. 2003;21(7):519–28.
38. Morgan OJ, Drust B, Ade JD, Robinson MA. Change of direction frequency off the ball: new perspectives in elite youth soccer. *Sci Med Footb*. 2022;6:473–82.
39. Niederer D, Engeroff T, Wilke J, Vogt L, Banzer W. Return to play, performance, and career duration after anterior cruciate ligament rupture: a case-control study in the five biggest football nations in Europe. *Scand J Med Sci Sports*. 2018;28:2226–33.
40. O'Brien J, Finch CF, Pruna R, McCall A. A new model for injury prevention in team sports: the Team-sport Injury Prevention (TIP) cycle. *Sci Med Footb*. 2019;3:77–80.
41. Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. *Br J Sports Med*. 2002;36:354–9.
42. Russell M, Benton D, Kingsley M. The effects of fatigue on soccer skills performed during a soccer match simulation. *Int J Sports Physiol Perform*. 2011;6(2):221–33.
43. Santamaria LJ, Webster KE. The effect of fatigue on lower-limb biomechanics during single-limb landings: a systematic review. *J Orthop Sports Phys Ther*. 2010;40:464–73.
44. Small K, McNaughton L, Greig M, Lovell R. Effect of timing of eccentric hamstring strengthening exercises during soccer training: implications for muscle fatigability. *J Strength Cond Res*. 2009;23(4):1077–83.
45. Tomeo E, Cesari P, Aglioti SM, Urgesi C. Fooling the kickers but not the goalkeepers: behavioral and neurophysiological correlates of fake action detection in soccer. *Cerebral Cortex*. 2013;23:2765–78.
46. Tsarhou C, Liveris NI, Xergia SA, Papageorgiou G, Kvist J, Tsepis E. ACL injury etiology in its context: a systems thinking, group model building approach. *J Clin Med*. 2024;13(16):4928.
47. van Mechelen W, Hlobil H, Kemper HCG. Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Med*. 1992;14:82–99.
48. Waldén M, Häggglund M, Magnusson H, Ekstrand J. ACL injuries in men's professional football: a 15-year prospective study on time trends and return-to-play rates reveals only 65% of players still play at the top level 3 years after ACL rupture. *Br J Sports Med*. 2016;50:744–50.
49. White A, Hills SP, Hobbs M, Cooke CB, Kilduff LP, Cook C, et al. The physical demands of professional soccer goalkeepers throughout a week-long competitive microcycle and transiently throughout match-play. *J Sports Sci*. 2020;38(8):848–54.
50. Wilmes E, De Ruiter CJ, Bastiaansen BJC, Goedhart EA, Brink MS, Van Der Helm FCT, et al. Associations between hamstring fatigue and sprint kinematics during a simulated football (soccer) match. *Med Sci Sports Exerc*. 2021;53(12):2586–95.
51. Zaffagnini S, Grassi A, Marcheggiani Muccioli GM, Tsapralis K, Ricci M, Bragonzoni L, et al. Return to sport after anterior cruciate ligament reconstruction in professional soccer players. *Knee*. 2014;21:731–5.

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Buckthorpe M, Paolo SD, Grassi A, Tosarelli F, Villa FD. Timing of ACL injuries during elite male football (soccer) matches—Impact of player position, substitutes, contact mechanisms, possession status and situational pattern: An analysis of 369 ACL injuries. *Knee Surg Sports Traumatol Arthrosc*. 2025;1–12. <https://doi.org/10.1002/ksa.70161>